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Evaluation of forage Amaranth (*Amaranthus hypochondriacus* l.) yield via comparing drought tolerance and susceptibility indices

Alireza Ahrar[1], Farzad Paknejad[1,*], Seyed Ali Tabatabaei[2], Fayaz Aghayari[1], Elias Soltani[3]

[1] *Department of Agronomy, Karaj Branch, Islamic Azad University, Karaj, Iran*
[2] *Seed and Plant Improvement Research Department, Yazd Agricultural and Natural Resources and Education Center, AREEO, Yazd, Iran*
[3] *Department of Agronomy and Plant Breeding (Abureyhan), University of Tehran, Tehran, Iran*
*Corresponding author email: farzadpaknejad@yahoo.com, https://orcid.org/0000-0003-0951-2072.

Abstract. In orther to investigate the influence of different drought stress levels on the quality and quantity yield of forage Amaranth, a set of split-plot analysis were carried out in randomized blocks design with three replicates during the 2018 and 2019 growing seasons. The main factor of this study was different irrigation levels (50, 60, 70, and 80 % of the plant available water depletion) and the sub-factor was considered to be three different forage Amaranth genotypes, including Cim, Kharkovski, and Loura. The results revealed that an increase in irrigation intervals especially in 80 % water-deficit condition, will lead to a decrement in the fresh and dry yields (62 and 50 %), a reduction of WP factor (50 %) and an increase of the dry matter and crude protein percentages regarding the control treatment. Furthermore, to specify the most significant stress indices from Principal Component analysis in different drought stress levels, Harmonic Mean was chosen as the best index to examine the tolerance of Amaranth cultivars to the drought condition. According to the 3D graph of the opted index correlation with the yields, it was concluded that while Loura presents a better yield under mild stress conditions, the Cim genotype has the highest performance under moderate and severe drought stress conditions.

Keywords. Amaranthus hypochondriacus, Forage, Drought, Stress tolerance indices.

INTRODUCTION

Amaranth (*Amaranthus spp.*) which is originally a native plant in Mexico and Central America is considered as a weed in many regions (Khan et al., 2019). However, for many others, it has proved to be a highly tolerant and valuable plant which brings about many different human usages. Since the Spanish conquest, it has been considered as cuisine and the main ingredient for various beverages due to the high rich content of protein, and the dietary minerals such as calcium, magnesium, phosphorus, and potassium (Adhikary et al., 2020; Svirskis, 2003). Moreover, not only because of the plant's excellent tolerance in harsh climates and its short growth period but also due to the relatively high yields compared to the seeding rate, there is a worldwide trend for using it as a forage crop for ruminants, rabbits, pigs, and poultries (Leukebandara et al., 2019; Obua et al., 2012; Peiretti, 2018; Purwin et al., 2019).

In Nigeria, the effects of intercropping and fertilizer applications on the yield and nutritive value of Amaranth and maize were studied as a forage crop. The study revealed that the fertilizer which is used augments the Dry Matter yields and Crude Protein concentration of Amaranth and Amaranth/maize intercropping mixtures (Olorunnisomo and Ayodele, 2009). In another study, Sokoto and Johnbosco (2017) examined the yield and growth of Amaranths also in Nigeria. They applied 2 varieties of the plant with four different seed rates. Their findings indicated that although the plant height is not severely affected by the seed rates at 2 Weeks After Planting but at 4, 6, and 8 WAP the plants with a higher seed rate were obviously taller than the others. The effect of organic fertilizers on the same factors (yield and growth) also was investigated by Dlamini et al., (2020), they recommended stillage as a good choice for the farmers who prefer organic fertilizers in planting Amaranths.

On the other hand, ever since there was agriculture, drought was always considered a problem in the hot and dry regions of the world. The drought stress can affect the plant from morphological, physiological and biochemical aspects (Anjum et al., 2011; Gao et al., 2020). A study was conducted by Liu and Stützel (2002) to observe the leaf water relations and osmotic adjustment of Amaranth in dry soil conditions. Two years later in another research, they examined biomass production, partitioning, and water use efficiency of four different genotypes of Amaranth. They stated that the Specific Leaf Area and Water Use Efficiency of the plant were affected by the lack of water in all types but not with identical behavior (Liu and Stützel, 2004).

Despite Amaranths mentioned outstanding applications, research on the responses of forage Amaranths to the drought stresses was not carried out, adequately. But in other species of Amaranth, for example, grain for human consumption, a study was conducted in Brazil on the response of two Amaranth species (*Amaranthus caudatus* and *Amaranthus cruentus*) to water deficit stress. The results showed that with increasing the stress the amount of root dry mass decreased while the shoot part augmented. Also in the *A. cruentus* specimen water productivity decreased with increasing water stress (Da Silva et al., 2019).

In Japan, four vegetable Amaranth cultivars were examined under the drought stress conditions. It was seen that due to its fine supply of the necessary elements under stress conditions, the plant could be an appropriate crop in semi-arid and dry regions and also during dry seasons, but it was highly dependent on the genotypes (Sarker and Oba, 2018). In Russia, also Amaranth responses to the soil drought in a greenhouse were investigated by Valdayskikh et al. (2019). Furthermore, Jamalluddin et al. (2019) tried to evaluate the Transpiration Efficiency of Amaranth in response to drought. They explored the TE factor for 9 accessions belonging to Amaranths and stated that the TE factor was much higher in the water-deficient plants compared to the water-sufficient plants. In another investigation Grantz et al., (2019) examined the tolerance to ozone and drought in *Amaranthus tuberculatus*. Although in their study, Amaranth was considered as a weed, but according to their results, the plant productivity, Leaf mass per unit area, and root mass per unit leaf area were not significantly affected by the drought.

Due to the increasing demand for animal feed and the lack of fodder Amaranth scientific investigations, it seems essential to study different qualifications and specifications of the plant. Thereby, regarding the inadequacy of awareness about the drought stress on the Amaranth as forage, this study aimed to investigate the quantity and quality of leaves and stems of three Amaranth cultivars for forage usage and it was tried to evaluate the resistance and performance of this plant when sown under different levels of water deficit, via comparisons of stress tolerance and susceptibility indices. Also, in this research, we sought to achieve maximum water productivity with a non-significant statistical reduction in forage yield.

MATERIALS AND METHODS

Plant materials and growth conditions

Seeds of three forage Amaranth cultivars were used in this study namely Cim, Kharkovski and loura. Seeds

Tab. 1. Meteorological data of the experimental sites. (During the experiments).

Month	Temperature (°C)				Relative Humidity (%)	Evaporation Rate (mm)	Monthly Rainfall (mm)
	Mean of Max.	Mean of Min.	Daily ave.	Mean of soil (0-30 cm)			
May 2018	34.9	21.0	28.3	30.1	19.7	12.6	7.8
June 2018	39.8	24.7	33.1	36.1	8.5	15.9	0
July 2018	39.2	25.8	33.0	37.4	11.2	16.3	0
May 2019	30.7	18.3	24.7	27.4	28.7	9.8	8.5
June 2019	39.0	25.2	32.4	35.5	12.6	15.0	0
July 2019	39.3	24.3	32.9	35.8	7.4	16.0	0

Tab. 2. physicochemical properties of the soil in the field before planting (0–30 cm depth).

Year	K (p.p.m)	P (p.p.m)	N (%)	O.C (%)	S.A.R	pH	EC (dS/m)	FC Θ_V	PWP Θ_V	Soil texture
2018	157	13.6	0.017	0.205	3.63	7.2	4.9	24.4	10.8	Sandy clay loam
2019	138	7.3	0.021	0.254	2.8	7.2	4.5	-	-	Sandy clay loam

O.C: Organic Carbon, S.A.R: Sodium Adsorption Ratio, EC: Electrical Conductivity, FC: Field Capacity, PWP: Permanent Wilting Point, Θ_V: Volumetric Humidity.

were planted at Agricultural Research Station located in Yazd, Iran (31°54´30´´N and 54°16´20´´W). The station is located at 1215 m above the sea level and according to Koppen climate classification (Kottek et al. 2006), it has summers with dry and warm climates (See Table 1). The genotypes were planted in the first week of May during 2018 and 2019 in 40m^2 plots (fifteen 4-meter-long rows). The spacing was 10 cm and 60 cm between the plants and the rows, respectively (Planting density =166000 plants.ha^{-1}). In addition, the soil properties of the study site are listed in Table 2.

Treatments

One of the factors was devised to be the four levels of soil moisture: 1. No drought stress (i.e. 50 % moisture depletion of plant available water, normal condition), 2. Mild water deficit (60 % moisture depletion), 3. Medium water deficit (70 % moisture depletion) and 4. Severe water deficit (80 % moisture depletion). Soil moisture was checked with TDR (Connector and Buriable Probes, 6050X1 TRASE System I Analyzer, Soilmoisture Equipment Corp., United States). In the first step, Field Capacity (FC) and Permanent Wilting Point (PWP) were calculated in the field and the pots, respectively (table 2), and afterwards, Plant Available Water (PAW) was computed from PAW=FC-PWP (Kirkham, 2005).

Firstly, all test cases were irrigated at the same time from planting to the seedling establishment stage as designed in the control conditions (50% moisture depletion of plant available water). Afterwards, the stress treatments were applied (60, 70 and 80 % moisture depletion of plant available water). The amount of irrigation was determined by the irrigation meter of each plot, and Table 3 presents the number of irrigation times and the amount of irrigation in two years.

Another factor was the three different Amaranth genotypes used in this study. All of the specimens belong to the *Amaranthus hypochondriacus* specie. It is worth mentioning that these cultivars were selected, according to the available species of Amaranth in Iran recommended by the Iranian state organization (AREEO)[1], and also due to the conservation of genetic diversity. Seeds of all cultivars had a yellow cream color, and unlike Kharkovski's green color; the Loura and Cim plants were a spectrum of the red color (Rahnama and Safaeie, 2017).

[1] Agricultural Research, Education and Extension Organization

Tab. 3. The number of irrigation times and the amount of irrigation in two years.

Irrigation treatments	Number of irrigation times		The cumulative amount of irrigation (m^3 ha^{-1})	
	Year: 2018	Year: 2019	Year: 2018	Year: 2019
Normal condition (50% moisture depletion)	12	12	12307	12000
Mild stress (60% moisture depletion)	11	11	11282	11000
Medium stress (70% moisture depletion)	10	10	10256	10000
Severe stress (80% moisture depletion)	9	9	9230	9000

Yield parameters

Plants per experimental plot were harvested to obtain biologic yield at 50 % flowering. The Sampling process was carried out from four middle lines of each sub-plot with 4 m^2 by removing the marginal effect. Then, in order to obtain the dry weight of the plant, the samples were incubated for 48 hours in the oven at 75 ° C. At the same time, fresh and dry weights of the leaves and stems of some random bushes were measured (Rahnama and Safaeie, 2017).

For agricultural systems, Water Productivity (WP) is a factor that indicates the production rate of a plant with respect to the consumed water. In this survey, water productivity was calculated by the following equation.

$$WP = \frac{fresh\ forage\ yield}{consuming\ water}$$ (kg m^{-3}) (Cook et al., 2006)

Also, the Leaf to Stem Ratio (LSR) in Amaranth is obtained from the division of fresh leaf to fresh stem weight (Rahnama and Safaeie, 2017). Likewise, the dry matter (DM) content of the crop represents the amount of residual dry material when the water content of the plant has been deducted, which is obtained from the ratio of dry plant yield to fresh plant yield (Olorunnisomo and Ayodele, 2009). The Kjeldahl method was applied to calculate the total nitrogen content for the plants with a ratio of 1: 1 leaf and stem (Kjeldahl, 1883). Then the amount of Crude Protein (CP) was calculated based on the nitrogen value (Onyango, 2010).

Tab. 4. Various drought stress index equations.

Mean Production	$MP = (Y_P + Y_S)/2$	(Rosielle and Hamblin 1981)
Tolerance Index	$Tol = Y_P - Y_S$	(Rosielle and Hamblin 1981)
Geometric Mean Productivity	$GMP = \sqrt{Y_S \cdot Y_P}$	(Fernandez 1992)
Stress Index	$SI = 1 - (\overline{Y}_S / \overline{Y}_P)$	(Fischer and Maurer 1978)
Stress Susceptibility Index	$SSI = (1 - Y_S/Y_P)/SI$	(Fischer and Maurer 1978)
Stress Tolerance Index	$STI = (Y_S \cdot Y_P)/(\overline{Y}_P)^2$	(Fernandez 1992)
Yield Stability Index	$YSI = Y_S/Y_P$	(Bouslama and Schapaugh 1984)
Harmonic Mean	$HM = (2 \cdot Y_P \cdot Y_S)/(Y_P + Y_S)$	(Fernandez 1992)
Yield reduction ratio	$Yr = 1 - (Y_S/Y_P)$	(Gavuzzi et al. 1997)
Relative Drought Index	$RDI = (Y_S/Y_P)/(\overline{Y}_S/\overline{Y}_P)$	(Bidinger et al. 1987)

Drought indices

Various stress indices were applied in this study to carry out the drought stress analysis in different fodder genotypes of Amaranths. The plants' drought stress sensitivity and tolerance are investigated using the following equations.

In the above equations, and are the mean yields of a given genotype evaluated under the drought stress and non-stress conditions, respectively. Also, and are the mean seed yields overall genotypes evaluated under the drought stress and non-stress conditions, respectively.

Experimental design and data analysis

A split-plot analysis was applied in some randomized complete blocks design in two successive years. The main factor was four levels of water stress and the sub-factor was three cultivars of forage Amaranth. Each treatment was repeated three times and wherever significant differences were obtained by the ANOVA, a comparative Duncan test (P≤0.05) was carried out. Bartlett test was applied to ensure the homogeneity of error variances (Bartlett, 1937). All of the traits were analyzed by combined analysis because of homogeneous error variances for two consecutive years. Furthermore, the obtained data were analyzed using SAS v 9.4 (SAS Institute Inc. USA), and the principal component analysis was done using the Statgraphics 18 Software (Statgraphics Technologies, Inc. The Plains, Virginia).

RESULTS AND DISCUSSION

Yield Parameters

According to table 5, no significant difference was observed in the studied behaviors of the cases in the two test years (i.e. 2018 and 2019). Moreover, amongst all other active parameters of the main factor (various levels of the drought stress) a significant difference ($p<0.01$) was observed. Besides, the forage fresh and dry yields, as well as the water productivity in the Control condition (50 % of the plant available water depletion) were clearly higher than those of other treatments, which was also reported by several other researchers (Alvar-Beltrán et al., 2019; Jaleel et al., 2009). Since our target product was the leaves and stems of the plants and the plant's life cycle was relatively short, therefore the drought stress durations after the establishment of the seedlings were quite short, which leads to a decrement of WP with an increment of the drought stress levels. However, in the 3 other parameters (LSR, DM, and CP) the results in the 80% water-depletion treatment were relatively higher than the other treatments.

Also in the genotypes factor, differences ($p<0.05$) were obtained in the LSR, CP and fresh yield parameters between treatments, which is due to the genetic diversity of the genotypes. According to the field experiments, the LSR and fresh yield parameters of Cim and Loura genotypes were remarkably higher than Kharkovski but on the other hand, the Crude Protein percentage of the Kharkovski genotype was significantly higher than the others.

The interactions of drought stress levels and cultivars revealed that in the control condition Cim and Loura genotypes offered the best results in the fresh and dry yield parameters, while they had a significant difference with Kharkovski. But, it was interesting to see, although Loura had the highest result in the control condition, the genotype was quite weak facing the drought stress. It was seen that the rate of decrement in the fresh and dry yields of the genotypes subjected to the drought stress was much steeper for Loura. Meanwhile, Cim offers an acceptable productivity level in the control condition and also it shows a better tolerance to the water deficit under moderate and severe drought stresses. The reduction of plants' yields under drought stress conditions has been reported vastly by other researchers in the open literature (Bidinger et al., 1987; Da Silva et al., 2019; Sarker and oba, 2018). Under mild drought stress, Loura water productivity did not show any significant difference to Cim and Loura genotypes in the control condition. With the augmentation of the drought stress level, we witness a decrease in water productivity in all cultivars which is also verified by other researchers (Da Silva et al., 2019). In this parameter also Cim presented a better performance facing the drought stress, regarding Loura and Kharkovski genotypes.

However, the three different genotypes of Amaranth show different behaviors from the fresh weight of leaves to the stem ratio per plant parameter point of view. As was observed in the control condition, Cim cultivar offers the highest LSR, but Loura didn't show a distinguishable difference between its control and the 80 % water deficit conditions. It goes without saying that LSR is a division of two independent parameters (leaf to stem). In the control condition due to the maximum growth and competition of the plants, the numerator (fresh leaf weight) of the fraction exceeds the denominator. On the other hand, in the 80% water-deficit case, despite remarkable leaf and stem weight drops, the stem weight decreased more drastically. Hence, the denominator reduces and it causes the no-significance difference level between the control and severe stress conditions.

Furthermore, Kharkovski cultivar offered a relatively higher percentage of crude protein in the 80% water-deficit condition with respect to the other genotypes×drought stress levels. The CP behavior with a mild variation rate decreases from the severe stress to control condition in all genotypes. This trend also was reported by others (Kuchenmeister et al., 2013). Besides, Nabhan (1986) stated that in some wild cultivars of the canopy, the nitrogen levels are increased but prolonging the drought condition can cause a decrement in the nitrogen content of leaves due to the nitrogen transport to the foliage and seeds. Also, the dry matter percentage did not show any significant difference between the cases.

Comparison of the genotypes based on tolerance indices

The most popular tolerance and susceptibility index equations which are presented in Table 4 were applied to investigate the resistance of Amaranths different genotypes to the drought stress. It is also worth mentioning that the best usage of Amaranths plant is as fresh or silage fodder (Stordahl et al. 1999), thus in this research the stress indices are used for the fresh forage, only and the results can be seen in table 6.

It is known that for RDI, SSI, TOL, and Yr indices, lower values represent higher resistance of the plant to the drought stress, while for YP, YS, GMP, MP, YSI, STI, and HM indices higher values are representing higher tolerance. However, for a better understanding of the

Tab. 5. Effect of water stress on the yield parameters of three genotypes of forage Amaranth in the two successive years.

Treatment	Fresh Yield (ton ha^{-1})	Dry Yield (ton ha^{-1})	Water Productivity (kg m^{-3})	Leaf to Stem Ratio	Dry Matter (%)	Crude Protein (%)
			Year			
2018	35.52	5.63	3.21	0.51	16.56	15.27
2019	36.71	5.56	3.39	0.50	15.76	15.16
significance	ns	ns	ns	ns	ns	ns
			Drought stress level			
water-deficit 50%	53.65 a	7.59 a	4.42 a	0.51 b	14.16 c	13.50 d
water-deficit 60%	41.72 b	6.30 b	3.74 b	0.50 bc	15.11 c	14.62 c
water-deficit 70%	28.98 c	4.78 c	2.86 c	0.49 c	16.66 b	15.66 b
water-deficit 80%	20.12 d	3.74 c	2.21 d	0.54 a	18.75 a	17.11 a
significance	**	**	**	**	**	**
			Genotype			
Cim (C)	38.55 a	5.91	3.54	0.53 a	15.81	14.66 b
Kharkovski (Kh)	31.99 b	5.04	2.94	0.46 b	16.22	15.94 a
Loura(L)	37.82 a	5.86	3.44	0.54 a	16.47	15.07 b
significance	*	ns	ns	*	ns	*
			Interaction			
water-deficit 50%×(C)	56.24 a	8.08 a	4.63 ab	0.60 a	14.38	13.02 h
water-deficit 50%× (Kh)	46.32 bc	6.56 bc	3.81 c	0.35 g	14.15	14.35 f
water-deficit 50%×(L)	58.40 a	8.14 a	4.81 ab	0.58 b	13.93	13.13 h
water-deficit 60%×(C)	42.19 c	6.20 cd	3.79 c	0.46 f	14.67	13.95 g
water-deficit 60%× (Kh)	36.24 d	5.56 de	3.25 d	0.53 c	15.41	14.86 e
water-deficit 60%×(L)	46.74 b	7.13 b	4.19 bc	0.49 de	15.26	15.05 e
water-deficit 70%×(C)	33.15 d	5.23 e	3.27 d	0.50 de	15.79	14.79 e
water-deficit 70%× (Kh)	27.51 e	4.86 ef	2.72 e	0.46 f	17.71	16.56 c
water-deficit 70%×(L)	26.28 ef	4.25 fg	2.59 ef	0.52 d	16.47	15.65 d
water-deficit 80%×(C)	22.62 fg	4.15 fg	2.48 ef	0.55 c	18.42	16.88 b
water-deficit 80%× (Kh)	17.88 h	3.16 h	1.96 g	0.49 e	17.61	17.98 a
water-deficit 80%×(L)	19.85 gh	3.92 gh	2.18 fg	0.58 b	20.21	16.47 c
significance	*	*	*	**	ns	**
CV (%)	12.02	12.98	12.86	14.56	7.04	5.02

Values within one column followed by different letters are significantly different at $P<0.05$ according to Duncan's test. ns, no significance ($P<0.05$). *, **, significance at $P<0.05$, $P<0.01$, respectively.

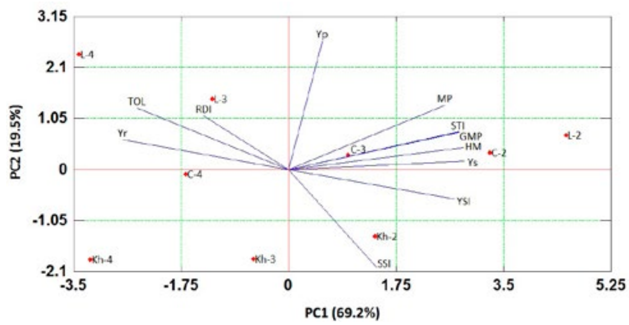

Fig. 1. Biplot principal component analysis (PCA) of various drought resistance indices in three forage Amaranth cultivars. Note: PC1 and PC2; First and second principal component respectively. C: Cim, KH: Kharkovski, L: Loura. 2, 3 and 4: 60, 70 and 80% plant available water depletion, respectively.

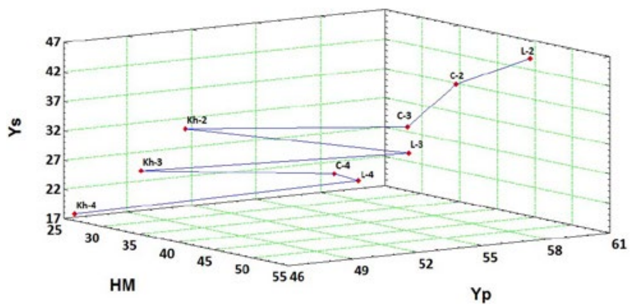

Fig. 2. Graphic display 3D biplot of the best genotypes for Harmonic Mean and potential (control) yield and fresh forage yield under drought stress. Note: C: Cim, KH: Kharkovski, L: Loura. 2, 3 and 4: 60, 70 and 80% plant available water depletion, respectively.

results of table 6, it is required to investigate the mutual relationship of these indices together.

Principal Component Analysis simplifies complex data via converting several associated variables into a smaller number of variables as main components. The first component indicates the maximum variability in the data as compared to the others. This is while in this study, Component 1 and 2 accounted for approximately 89% of the variation (Supplementary Table 7).

Table 8 presents the correlation results of the average values for the three genotypes in two successive years between the fresh forage yield and stress indices in the normal and stress condition, independently. In the mild stress condition HM, STI, GMP, TOL, MP indices and in the moderate stress condition Yr, Ysi, MP, TOL indices had the highest correlation with the yield of the no-stress condition Yp. Also in the severe stress condition, Tol and Mp indices presented the strongest correlation to the control yield. On the other hand, while in

Tab. 6. Tolerance and susceptibility indices three genotypes of forage Amaranth under conditions of drought stress in the two successive years.

Genotype	Yp	Ys	MP	TOL	GMP	SSI	STI	YSI	HM	Yr	RDI
Tolerance and susceptibility indices under mild drought stress											
Cim	56.24	42.19	49.21	14.05	48.65	0.98	2370.16	0.76	48.09	0.24	1.01
Kharkovski	46.32	36.24	41.28	10.08	40.81	0.94	1671.91	0.80	40.36	0.20	1.02
Loura	58.40	46.74	52.57	11.66	52.16	1.00	2735.08	0.81	51.76	0.19	1.00
Tolerance and susceptibility indices under moderate drought stress											
Cim	56.24	33.15	44.70	23.09	43.08	0.99	1861.41	0.59	41.54	0.41	1.01
Kharkovski	46.32	27.51	36.91	18.81	35.65	0.99	1282.43	0.60	34.43	0.40	1.01
Loura	58.40	26.28	42.34	32.12	38.73	0.80	1515.89	0.46	35.56	0.54	1.02
Tolerance and susceptibility indices under severe drought stress											
Cim	56.24	22.62	39.43	33.63	35.32	0.98	1270.19	0.41	31.81	0.59	1.00
Kharkovski	46.32	17.88	32.10	28.44	28.66	0.99	833.49	0.39	25.64	0.61	1.01
Loura	58.40	19.85	39.13	38.55	33.46	0.99	1144.34	0.35	28.88	0.65	1.02

Yp, fresh mean yield of the genotype under non-stress conditions; Ys, fresh mean yield of the genotype under stress conditions; MP, mean productivity; TOL, tolerance; GMP, geometric mean productivity; SSI, stress susceptibility index; STI, stress tolerance index; YSI, yield stability index; HM, harmonic mean; Yr, Yield reduction rate; RDI, relative drought index.

all drought stress levels Tol, SSI, YSI, Yr, RDI indices did not have any significant correlation with the yield of the stress condition (Ys), other indices of Mp, GMP, STI, HM demonstrated a positive correlation ($P<0.01$) to Ys.

In order to specify the most applicable indices, the Principal Component Analysis (PCA) was carried out. According to the biplot graph of figure 1, the first and second components represented 69.2 and 19.5 % of the variation with the different attributes, respectively. Additionally, since Ys and HM indices in the first component and Yp index in the second component can probe the variations in the best way, they were applied in this study.

Also for a precise study of the cultivars, their Harmonic Mean (HM) index is investigated in the no-stress and under-stress conditions. The result is illustrated in figure 2, in which the horizontal axis indicates the cultivars' priority from the HM index point of view. It is obvious at the first look, that Loura possesses the highest yield in the mild stress condition, but it can be seen that its tolerance to the drought stress is much weaker regarding other genotypes. On the other hand, not only Cim offers the highest HM index in the severe stress condition, but also its performance in the moderate stress condition is higher than Kharkovski in the mild stress condition. This can prove that Cim cultivar provides much better resistance to drought stress with relatively high productivity.

Tab. 7. Principal component analysis of stress tolerance indices in three genotypes of forage Amaranth under conditions of drought stress.

Indices	Component				
	1	2	3	4	5
Yp	0.069	0.628	-0.319	0.180	0.311
Ys	0.361	0.039	0.080	-0.043	-0.120
MP	0.321	0.313	-0.079	0.046	0.043
TOL	-0.311	0.300	-0.249	0.139	0.283
GMP	0.349	0.184	-0.031	0.075	-0.033
SSI	0.181	-0.477	-0.416	0.747	0.006
STI	0.348	0.181	-0.057	-0.036	-0.597
YSI	0.340	-0.145	0.254	-0.053	0.464
HM	0.358	0.108	0.002	0.071	-0.063
Yr	-0.340	0.145	-0.254	0.053	-0.464
RDI	-0.175	0.261	0.720	0.607	-0.119
Eigenvalue	7.604	2.142	1.106	0.132	0.014
Percent of Variance	69.126	19.476	10.054	1.200	0.144
Cumulative Percentage	69.126	88.602	98.656	99.856	100

CONCLUSIONS

Despite its tolerance to the harsh weather and wonderful applications in both food and forage industries in the world, it seems that the forage Amaranth plant is not appreciated by many researchers. In the present study, the growth and yield of three different genotypes of forage Amaranth were investigated under various drought stress levels in Yazd - Iran in two successive years. The results revealed that the plant is highly affected by water deficit and the water productivity parameter (WP) expe-

Tab. 8. The correlation coefficient between the different levels of tolerance and susceptibility to water deficit in the average of three genotypes of forage Amaranth in the two successive years.

	YS	MP	TOL	GMP	SSI	STI	YSI	HM	Yr	RDI
Tolerance and susceptibility indices under mild drought stress										
	YS	MP	TOL	GMP	SSI	STI	YSI	HM	Yr	RDI
YP	0.52*	0.91**	0.72**	0.88**	0.43ns	0.88**	-0.58*	0.84**	0.58*	-0.48*
YS		0.82**	-0.21ns	0.86**	-0.31ns	0.86**	0.38ns	0.9**	-0.38ns	0.28ns
MP			0.38ns	0.99**	0.14ns	0.99**	-0.21ns	0.99**	0.21ns	-0.19ns
TOL				0.31ns	0.74**	0.31ns	-0.97**	0.24ns	0.97**	-0.77**
GMP					0.09ns	0.99**	-0.14ns	0.99**	0.14ns	-0.13ns
SSI						0.09ns	-0.82**	0.04ns	0.82**	-0.97**
STI							-0.13ns	0.99**	0.13ns	-0.13ns
YSI								-0.07ns	-1**	0.83**
HM									0.07ns	-0.07ns
Yr										-0.83**
Tolerance and susceptibility indices under moderate drought stress										
	YS	MP	TOL	GMP	SSI	STI	YSI	HM	Yr	RDI
YP	-0.04ns	0.82**	0.83**	0.54*	0.16ns	0.54*	-0.66**	0.28ns	0.66**	-0.39ns
YS		0.82**	-0.21ns	0.86**	-0.31ns	0.86**	0.38ns	0.9**	-0.38ns	0.28ns
MP			0.36ns	0.93**	-0.11ns	0.92**	-0.11ns	0.78**	0.11ns	0.06ns
TOL				-0.01ns	0.37ns	-0.01ns	-0.96**	-0.3ns	0.96**	-0.69**
GMP					-0.24ns	0.99**	0.27ns	0.96**	-0.27ns	0.34ns
SSI						-0.23ns	-0.47*	-0.32ns	0.47*	-0.87**
STI							0.26ns	0.96**	-0.26ns	0.33ns
YSI								0.52*	-1**	0.78**
HM									-0.52*	0.52*
Yr										-0.78**
Tolerance and susceptibility indices under severe drought stress										
	YS	MP	TOL	GMP	SSI	STI	YSI	HM	Yr	RDI
YP	0.09ns	0.83**	0.8**	0.48*	-0.36ns	0.48*	-0.4ns	0.23ns	0.4ns	-0.28ns
YS		0.82**	-0.21ns	0.86**	-0.31ns	0.86**	0.38ns	0.9**	-0.38ns	0.28ns
MP			0.33ns	0.88**	-0.43ns	0.88**	0.18ns	0.73**	-0.18ns	0.24ns
TOL				-0.15ns	0.14ns	-0.15ns	-0.87**	-0.4ns	0.87**	-0.73**
GMP					-0.36ns	0.99**	0.61**	0.96**	-0.61**	0.61**
SSI						-0.36ns	-0.11ns	-0.29ns	0.11ns	-0.37ns
STI							0.6**	0.96**	-0.6**	0.61**
YSI								0.79**	-1**	0.9**
HM									-0.79**	0.76**
Yr										-0.9**

ns, no significance (P<0.05). *, **, significance at P<0.05, P<0.01, respectively.

rienced a significant drop of 15, 35, and 50 % for mild, moderate and severe drought stress conditions, respectively. It was also observed that despite its short life cycle, Amaranth plant offers acceptable quantity and quality of fodder which is why it is considered an excellent forage in many regions of the world. Moreover, the Principal Component analysis indicated that the HM index is one of the main components for the genotypes and according to this index, while Cim cultivar yield was higher than the other two genotypes, Kharkovski showed the weakest results. Since in this study the irrigation treatments were chosen according to the customary farming of the region. It seems that applying milder treatments in future researches could be effective in increasing water productivity. It may also lead to an increment in the yield.

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